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14. ABSTRACT

Emergency response operations would universally benefit by extending telemedicine to the most difficult and challenging environments. For example, the Air Force Pararescue Jumpers (PJ) and Combat Rescue Officers (CRO) perform rescue and life-saving measure in austere environments. Currently, Bluetooth® aided pen-and-paper systems are employed to collect and store medical data, from the time it is sensed to its dissemination. This is proving to be tedious and non-scalable, especially when the number of casualties is larger than the number of responders in a given mission. Pararescue Jumpers, Combat Rescue Officers and similar medical rescue agencies are seeking medical vital sign sensors and telemetry solutions for mass casualty responses in which a small team of medical rescuers must be able to rescue and sustain the life of multiple casualties in critical condition. Project Ripple, to be described in this paper, is meant to create a Medical Body Area Network (MBAN) of sensors to assist in triage and general physiological data collection in a disaster scenario. The system is demonstrates an improved alternative to existing Bluetooth® and pen-and-paper systems by streamlining the processes of data collection, storage, transfer, and visualization. Low-power, wireless devices that utilized open standards makeup the sensor network while custom mobile applications were used for the visualization of the sensor data. Also, flexible and generic sensor fusion architecture is being explored.

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MBAN; sensor fusion; pararescue

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RIPPLE: Scalable Medical Telemetry System for Supporting Combat Rescue

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***Abstract*— Emergency response operations would universally benefit by extending telemedicine to the most difficult and challenging environments. For example, the Air Force Pararescue Jumpers (PJ) and Combat Rescue Officers (CRO) perform rescue and life-saving measure in austere environments. Currently, Bluetooth® aided pen-and-paper systems are employed to collect and store medical data, from the time it is sensed to its dissemination. This is proving to be tedious and non-scalable, especially when the number of casualties is larger than the number of responders in a given mission. Pararescue Jumpers, Combat Rescue Officers and similar medical rescue agencies are seeking medical vital sign sensors and telemetry solutions for mass casualty responses in which a small team of medical rescuers must be able to rescue and sustain the life of multiple casualties in critical condition.**

Project Ripple, to be described in this paper, is meant to create a Medical Body Area Network (MBAN) of sensors to assist in triage and general physiological data collection in a disaster scenario. The system is demonstrates an improved alternative to existing Bluetooth® and pen-and-paper systems by streamlining the processes of data collection, storage, transfer, and visualization. Low-power, wireless devices that utilized open standards makeup the sensor network while custom mobile applications were used for the visualization of the sensor data. Also, flexible and generic sensor fusion architecture is being explored.

Keywords—MBAN; sensor fusion; pararescue

I. Introduction

Emergency response operations would universally benefit by extending telemedicine to the most difficult and challenging environments. For example, the Air Force Pararescue Jumpers (PJ) and Combat Rescue Officers (CRO) perform rescue and life-saving measure in austere environments. In the most recent conflicts, they are often called upon to respond to IED blasts, rocket attacks, or helicopter crashes. In other circumstances they are often involved in humanitarian response to natural disasters. We are currently seeking medical vital sign sensors and telemetry solutions for mass casualty responses in which a small team of Pararescue Jumpers must be able to rescue and sustain the life of multiple casualties in critical condition. The future medical sensing solutions will be small and lightweight, allowing the PJ to easily transport the devices to multiple patients. They will assist the lead PJ by providing real time status of all patients so that resources can be best prioritized to save as many lives as possible and to facilitate rapid extrication and transport of the casualties.

Additionally, designs based on emerging and open standards will make patient data available to all stakeholders in near real-time through advancements in ubiquitous and cloud computing. The fusion of sensor data and other information will improve command and control during incident response and will allow patient data to be available to the receiving emergency facilities prior to patient arrival. Predictive medical systems will use this sensor data and play an increasing role throughout the chain of patient care.

Ripple is a testbed for using physiological sensors to facilitate improved emergency response using ubiquitous and cloud computing technologies. The first stage of the project, presented in this paper, focuses on optimizing communication between wireless physiological sensors and patient monitoring devices used by emergency responders. The objective is to increase situation awareness with little additional effort on the part of the task saturated responder.

The traditional tools for evaluating and monitoring patients in a mass casualty event are triage tags, which are hand written tags that help the responder quickly document a patient assessment. Vital signs measurements are limited to those that can be manually measured by the responder without any sophisticated equipment, e.g. pulse and respiration rate.

Advances in wireless communications and miniaturization of electronics has led to the development and commercialization of compact, wearable sensors that can continuously monitor some patient vital signs. Our discussion with early adopters of these systems has revealed that the currently utilized wireless technologies interferes with their ability to efficiently monitor patients in all environments except those where a fixed wireless infrastructure can be established. Most systems that are being tested for emergency

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response utilize Bluetooth® because it is low power and allows any available smartphone or tablet device to be used for patient monitoring. During a patient hand-off, which occurs frequently and rapidly in a mass casualty response, a Bluetooth® device needs to be manually un-paired with the current monitoring device and paired with the monitoring devices of the next responder. If there are multiple Bluetooth® devices in range during the pairing, it can be difficult to quickly identify the device of interest.

What is needed for emergency response is to form a network of sensors and monitoring devices in which each and every monitoring device is capable of receiving data from each and every sensor. The existing systems which are capable of this are better suited for use in hospitals where a reliable network infrastructure can be maintained.

II. System Architecture

A. Exemplary Architecture

Ripple is a test-bed that allows us to experiment with a variety of subsystems to enable ubiquitous and reliable physiological monitoring in a mass casualty or disaster response. A specific architecture for this is not concretely defined but a set of core components is required. We have categorized these subsystems into the following taxonomy:

- Wireless patient sensor network: A network protocol is needed that can support a heterogeneous collection of sensors that can continue to functions seamlessly during patient handoffs. A network that support any-to-any routing is ideal for this purpose. Device and service discovery needs to be automated or very efficient and the wireless technology that is utilized needs to have minimal power requirements in order to facilitate the development of small sensors that can run unattended on small batteries for the duration of the rescue and transport.
- Mobile middleware: Services will need to be present on the local network to facilitate sharing of patient data and discovery of sensors and monitors. Many ubiquitous computing systems would rely on connections to remote cloud systems to accomplish this, but Ripple needs to support local patient monitoring when connection to the larger network or Internet is disrupted. It is important that this middleware is capable of being used on mobile computing devices because it will need to be transported and ideally, this middleware would be capable of operating on the computing devices that are used by the responders for patient monitoring.
- Cloud middleware: Patient data can be leveraged by a variety of other stakeholders through a cloud based infrastructure. A well designed architecture could support the sharing and fusion of patient data with predictive systems, command and control systems, and other information management and notification systems.
- User applications: All stakeholders will need patient data to be visualized and managed by applications that support the performance of their mission. The rescue personnel require applications that allow them to monitor all patients on a scene at once, or to look at a single patient in more detail and to manually add additional information to a patient's medical record.

B. Stage I Architecture

The first iteration of Ripple focused on the network of physiological sensors and responder monitoring devices. The primary objective was to prove a suitable alternative to the Bluetooth technology that limits the effectiveness of existing systems. A sensor network utilizing 802.15.4 [1] radios and IPv6 over Low power Wireless Personal Area Networks (6LoWPAN) was chosen. Table 1 summarizes the requirements supporting this selection

TABLE I. Suitability of Existing Wireless Technologies vs System Requirements

	Bluetooth®	Proprietary IEEE 802.15.4	IEEE 802.11	6LoWPAN with IEEE 802.15.4
Local any-to-any communication		✓	✓	✓
Standardized network of heterogeneous devices	✓		✓	✓
Global any-to-any communications			✓	✓
Ad-hoc device and service discovery	✓		✓	✓
Low power	✓	✓		✓
Mobility tolerance		✓	✓	✓

6LoWPAN is an IETF standard that provides an IPv6 adaptation layer for low power communication devices, particularly IEEE 802.15.4 devices. The result of employing this architecture is a wireless network of low power devices that behave similar to IEEE 802.11 devices, but with a lower power penalty at the expense of decreased throughput [2].

1) Sensor System

Idealized sensor platforms for emergency response are able to support the sensing of multiple signals. This reduces the burden of transporting multiple systems. For Ripple, we prototyped a system that combined a pulse oximeter, an electrocardiogram, a temperature probe, and and ARM 7, 802.15.4 System-on-Chip (SoC).

a) Ripple Sensor Components

- Hardware
  - Thermistor based dermal temperature probe
  - Nonin OEM III Module or Nonin XPOD Pulse Oximeters
  - Nonin 8000 series PureLight sensors
  - Shimmer Sensing ECG Board

Identify applicable sponsor/s here. If no sponsors, delete this text box (*sponsors*).

- o Redwire LLC Econotag MC13224 ARM7 802.15.4 SoC development kit
  - o Custom adapter board
- Software
  - o Contiki-OS
  - o Custom datagram transport application

2) Network

Ripple Sensors are part of a 6LoWPAN network. The network routing using the Routing Protocol for Low Power and Lossy Networks (RPL) to self-form a data acrylic graphs (DAG) which are intended to route traffic toward a limited number of collection points [3]. In theory, this would allow mobile sensors to switch collection points with limited loss of connection. The collection points reside outside of the link-local RPL network, on a standard TCP/IP network which is connected to the RPL network through a 6LoWPAN Border Router. An example network architecture network architecture including connections of to middleware and monitors is illustrated in Fig. 1.

3) Middleware

The system primarily relies upon a brokered publish/subscribe pattern of communication to ensure that newly connected clients and sensors can quickly be discovered and provided with needed information. Currently, the system uses a centralized information broker which runs on the same hardware as the 6LoWPAN Border Router, but this is not absolutely necessary.

The Information Broker is a program that acts as a bridge/buffer between the sensor network and the responder network. The broker serves two main purposes: local data management and communication between the sensor network and the responder network. This centralized framework was used for a couple reasons: reduce processing on the sensors by having no direct requests from responder devices to sensors and reduce traffic on the low-bandwidth sensor network as multiple requests for the same data comes from the Broker's buffer rather than directly from motes.

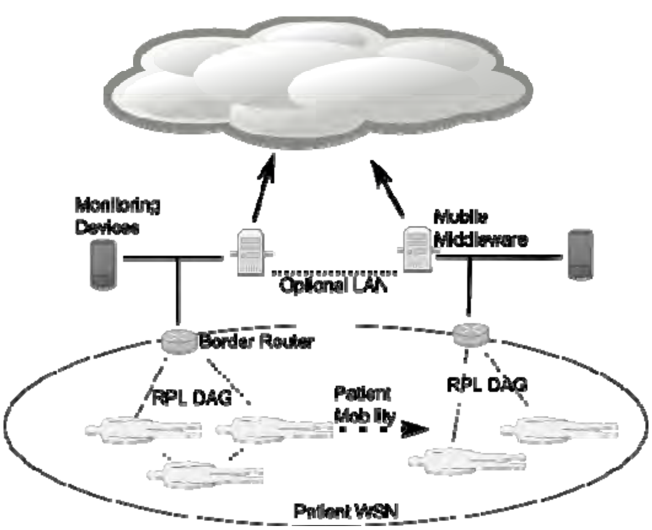

Fig. 1 Proposed network architecture to support patient handoffs and mobility

Patient data is stored in two forms in the broker: a small, temporary buffer to allow quick access to the lasts reading for a given patient and a SQL database for archival purposes. The broker will buffer the latest patient readings into an in-memory buffer to allow quick access when responders requests real-time streams for a specific patient. Patient data are archived using a SQL database. The patient information, such as id, name, and ip address, is stored in one table while vitals are stored in another table.

4) Human Computer Interaction

Mobile responders interact with patients connected to the wireless medical sensor network by way of the Ripple Android App (RAA). As the name suggests the RAA is a native android application, and is intended to be run on a large display format android-based device such as a tablet. The RAA offers 3 primary functions to the user: firstly the RAA acts as a high fidelity platform for visualizing patient health information, secondly as a network communication interface by which a responder can query sensor and submit manual health data. Lastly, the RAA is capable of acting as part of a delay tolerant caching network of other responders. The RAA is an integral part of the complete Ripple system.

The primary feature of the user interface is the simultaneous display of basic patient information for all patients, the more detailed display of a single patients medical data, and a third section that can be used to display geospatial data. A screenshot of the application is shown in Fig. 2. This user interface concept is compliments the needs of a responder to a military mass casualty with the display of all patient information facilitating the best use of limited medical resources, the individual patient section for managing the treatment of each patient, and the geospatial section for enhancing situational awareness of to combat related events, patient movements, and threats.

The basic patient information is presented as a horizontal scrolling bar across the top of the screen, with a tile for each

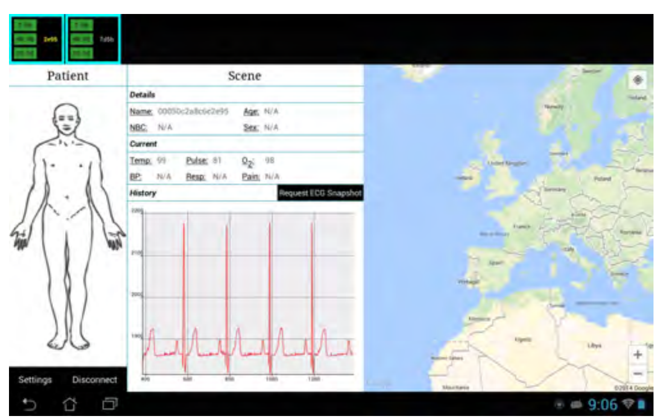

Fig. 2. Tablet user interface for patient monitoring

patient. The tile is color coded based on the patient status and

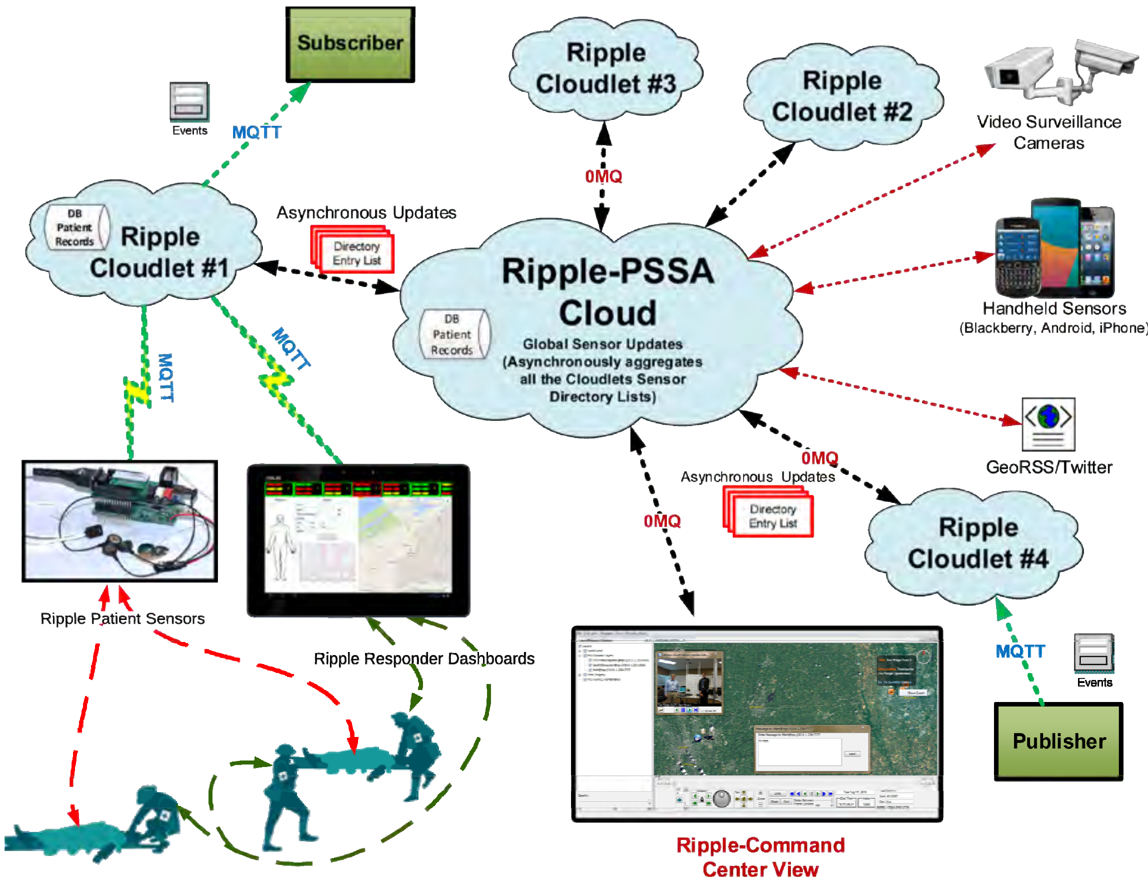

Fig. 3. Proposed future system with mobile cloudlet and cloud integration, as described in [5].

contains status bars showing the current heart rate, dissolved blood oxygen, and temperature of the patient. The tiles are also used as a selector for displaying individual patients information in the individual patient information display component.

The individual patients information is presented in the left half of the screen. It contains element that are common in many electronic triage applications including a map of the body for inputting medical notes that are associated to an area of the patients body. An area for inputting patient vitals and other patient identification information. And an area for display of streaming signals such as an electrocardiogram.

The right half of the screen is used for displaying geospatial information. The need for this in a military context needs little explanation as it is the primary use for most portable computers used in combat. In order to avoid having operators carry two mobile computing devices, for healthcare and combat purposes, this application proposes presenting this information on a single user interface.

III. Future Direction

To date, Ripple has focused primarily on the development of a local network for monitoring local patients. The next steps involve increasing the scope of our middleware infrastructure to promote ubiquitous sensing across a disaster area so that medical information can be shared with receiving facilities prior to patient arrival and with command and control for improved management of large scale disaster response and theatre situational awareness.

We envision future cyber physical systems that can provide vital sign and patient identity information to predictive computer systems that provide early warnings to responders when a patient is at increased risk, and systems that can fuse real time physiological data from both patients and responders with real time video from wide area surveillance systems providing command and control with improved situation awareness, and fusion system that combine smart city

technologies with ubiquitous health sensing to facilitate improved patient transportation during a disaster response.

In support of this vision, we are proposing an architecture for further research and development. The architecture shown in Fig. 3 replaces the information broker with a mobile cloudlet. The mobile cloudlet is a subset of middleware that would typically presented in the cloud for the purpose of supporting mission critical communication that cannot be put at risk by unreliable backhaul connections that are common in disaster areas and theatres of combat. This cloudlet for asynchronous connections to a generic cloud system that facilitates the dissemination of data to intelligent systems. We are currently experimenting and would be deploying Persistent Surveillance Storage Architecture (PSSA) [7] as the cloud system. The reasons to choose PSSA comes from the evidence that it has been successfully employed in time critical and data sensitive projects like [6] [4], targeted towards real-time situational awareness and situational understanding.

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